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(54) **TRIPLE OXYGEN SENSOR ARRANGEMENT**

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(52) **U.S. Cl.** **60/274**; 60/276; 60/285; 73/118.1; 73/489
(58) **Field of Search** 60/274, 276, 285; 73/118.1, 489

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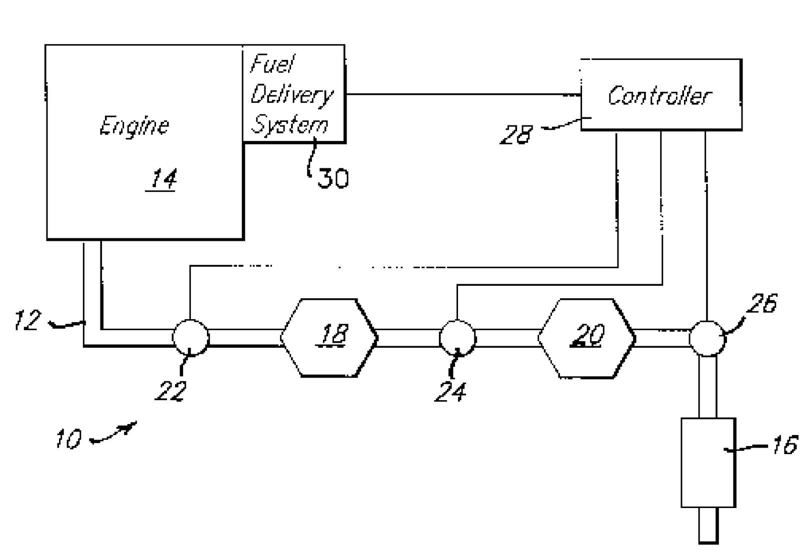
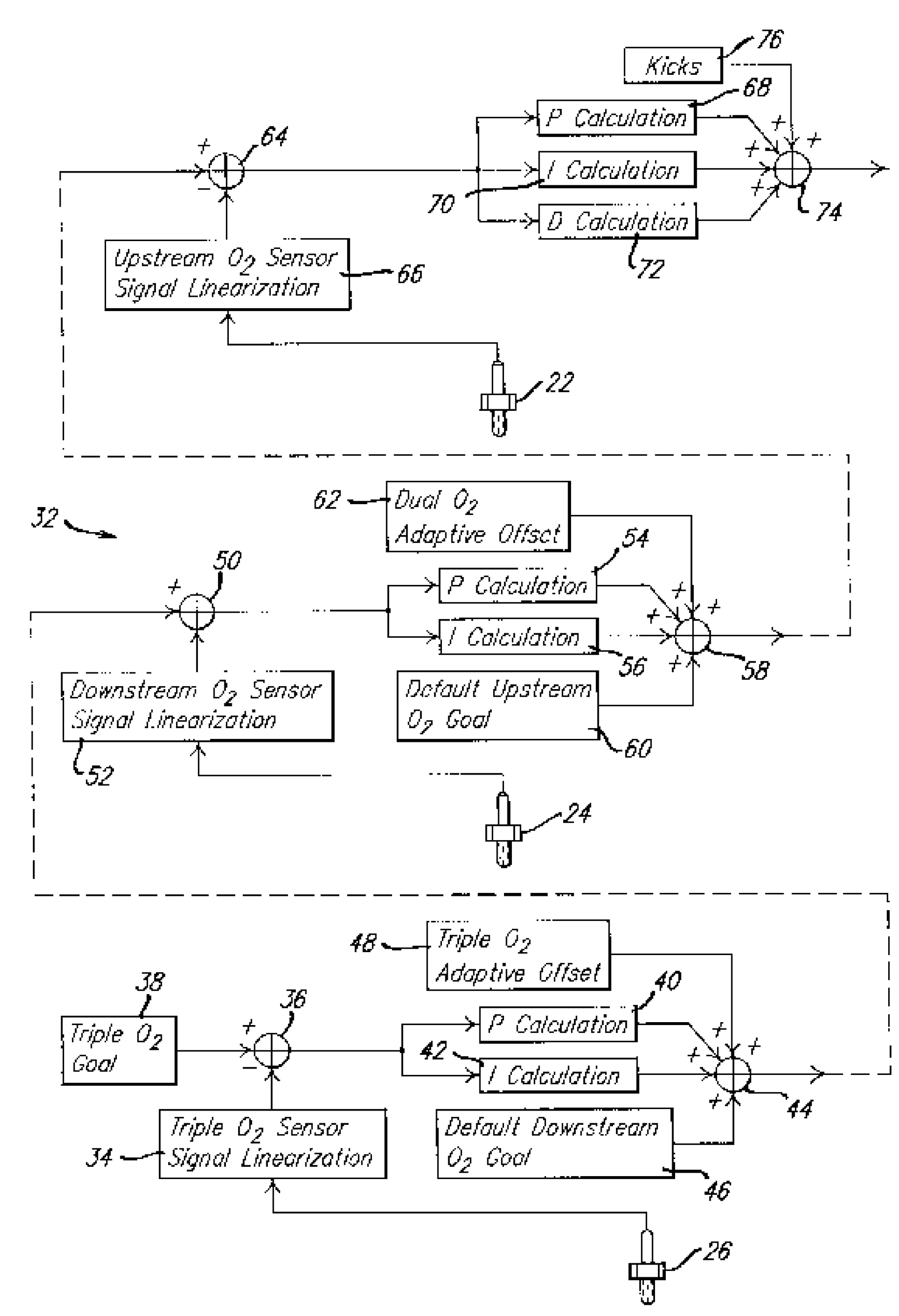
(57) **ABSTRACT**

An exhaust system is provided including two catalysts and three oxygen sensors. The second catalyst is disposed downstream of the first catalyst. The first oxygen sensor is disposed upstream of the first catalyst, the second oxygen sensor is disposed downstream of the first catalyst and upstream of the second catalyst, and the third oxygen sensor is disposed downstream of the second catalyst. A goal voltage corresponding to a desired level of nitrous oxide and hydrocarbon within the exhaust is provided for the third oxygen sensor. This goal voltage is based on engine RPM and MAP. The engine controller compares the goal voltage to an actual voltage generated by sensing the level of oxygen downstream of the second catalyst. Based on this comparison, an error value between the goal voltage and the actual voltage is obtained. This error value is converted into a goal voltage for the first oxygen sensor. An actual voltage generated by the first oxygen sensor sensing the amount of oxygen upstream of the first catalyst is compared to the goal voltage derived from the third oxygen sensor. The difference between the goal voltage and actual voltage is used to modulate the pulse width of a signal sent to the fuel injectors of an engine such that the amount of fuel delivered by the fuel injectors is modified. The second oxygen sensor generates an actual voltage corresponding to the amount of oxygen the second oxygen sensor senses downstream of the first catalyst and upstream of the second catalyst. Changes in the actual voltage generated by the second oxygen sensor are compared to changes in the actual voltage generated by the first oxygen sensor. By monitoring the nature of theses changes as they relate to one another, the performance of the first catalyst can be determined.

16 Claims, 4 Drawing Sheets





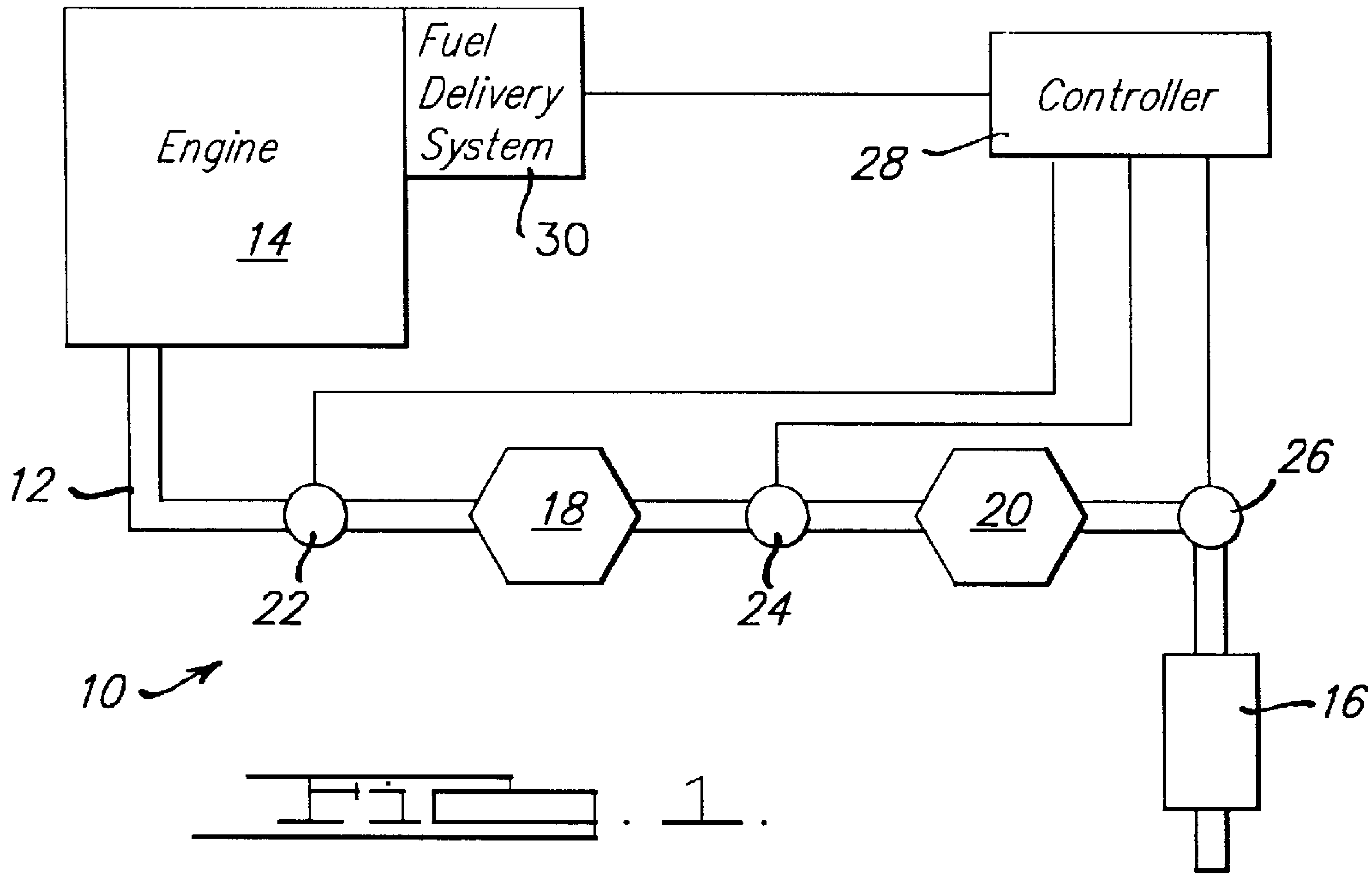

Fuel
Delivery
System
Controller
Engine
14
30
28
12
18
20
26
22
24
10
16

FIG. 1.

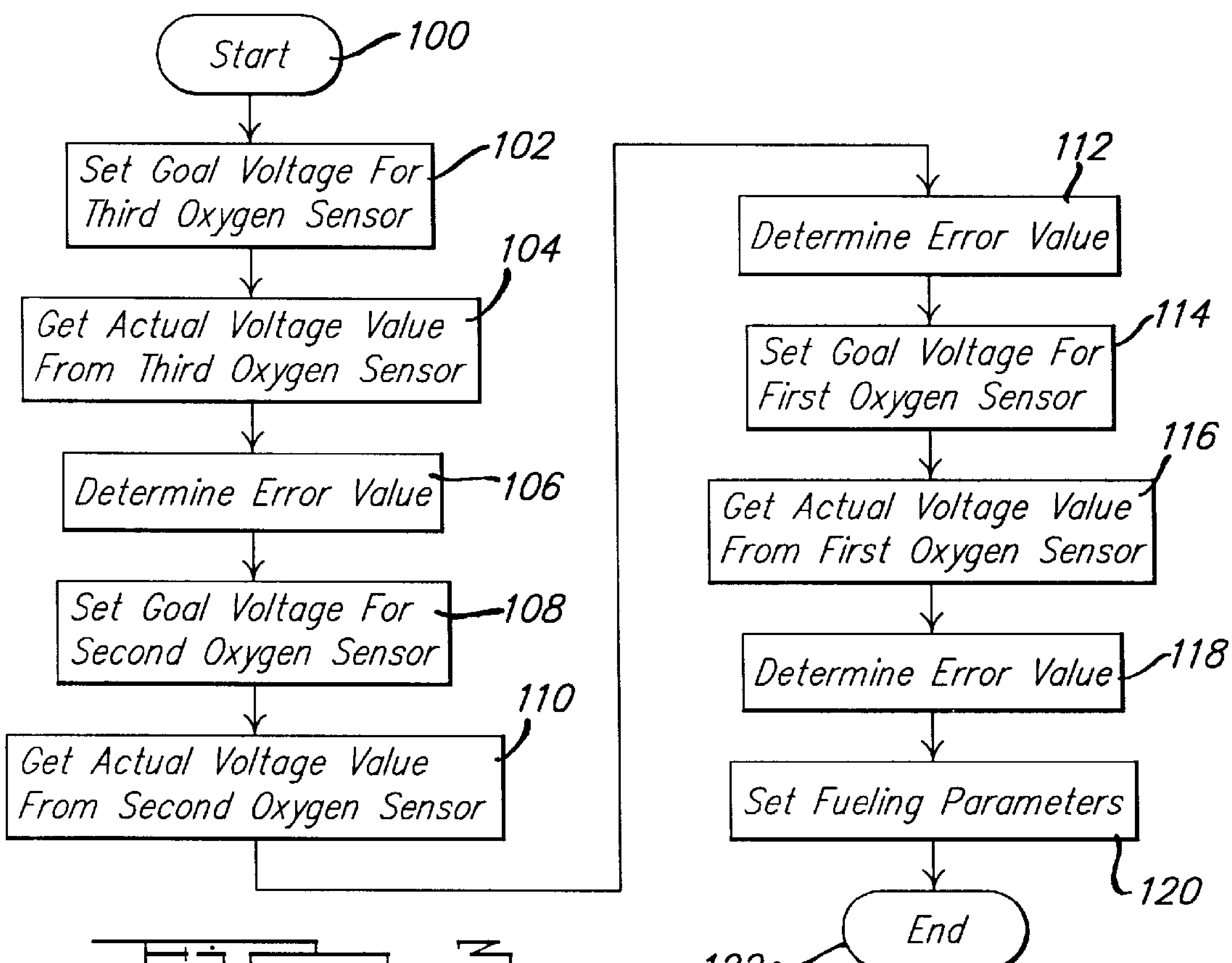

Start
100
Set Goal Voltage For Third Oxygen Sensor
102
Get Actual Voltage Value From Third Oxygen Sensor
104
Determine Error Value
106
Set Goal Voltage For Second Oxygen Sensor
108
Get Actual Voltage Value From Second Oxygen Sensor
110
Determine Error Value
112
Set Goal Voltage For First Oxygen Sensor
114
Get Actual Voltage Value From First Oxygen Sensor
116
Determine Error Value
118
Set Fueling Parameters
120
End
122

FIG. 3.

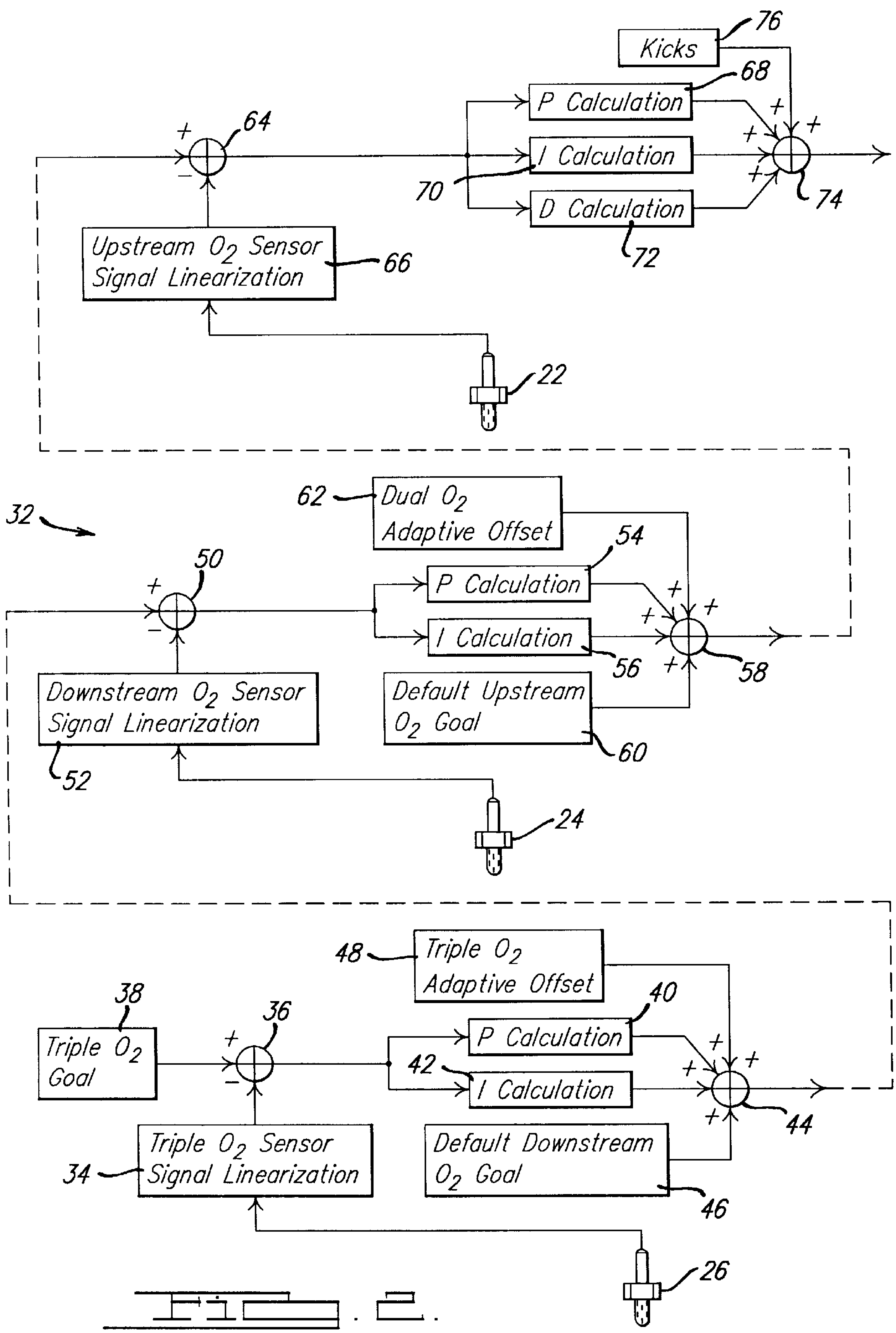

Kicks
76
P Calculation
68
I Calculation
D Calculation
70
72
74
64
Upstream O_2 Sensor Signal Linearization
66
22
32
62
Dual O_2 Adaptive Offset
54
50
P Calculation
I Calculation
56
58
Downstream O_2 Sensor Signal Linearization
52
Default Upstream O_2 Goal
60
24
48
Triple O_2 Adaptive Offset
40
38
Triple O_2 Goal
36
P Calculation
42
I Calculation
44
Triple O_2 Sensor Signal Linearization
34
Default Downstream O_2 Goal
46
26

FIG. 2.

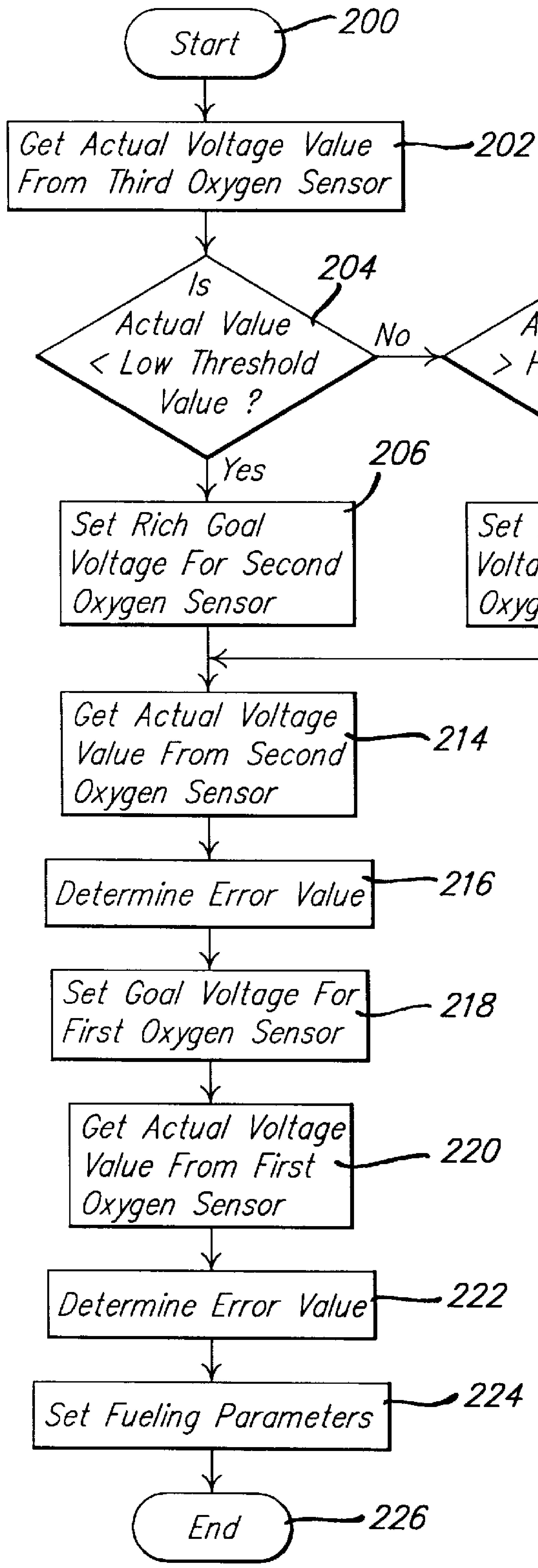

Start
200
Get Actual Voltage Value From Third Oxygen Sensor
202
Is Actual Value < Low Threshold Value ?
204
No
Is Actual Value > High Threshold Value ?
208
Yes
Yes
206
No
212
Set Rich Goal Voltage For Second Oxygen Sensor
Set Neutral Goal Voltage For Second Oxygen Sensor
Set Lean Goal Voltage For Second Oxygen Sensor
210
Get Actual Voltage Value From Second Oxygen Sensor
214
Determine Error Value
216
Set Goal Voltage For First Oxygen Sensor
218
Get Actual Voltage Value From First Oxygen Sensor
220
Determine Error Value
222
Set Fueling Parameters
224
End
226

FIG. 4.

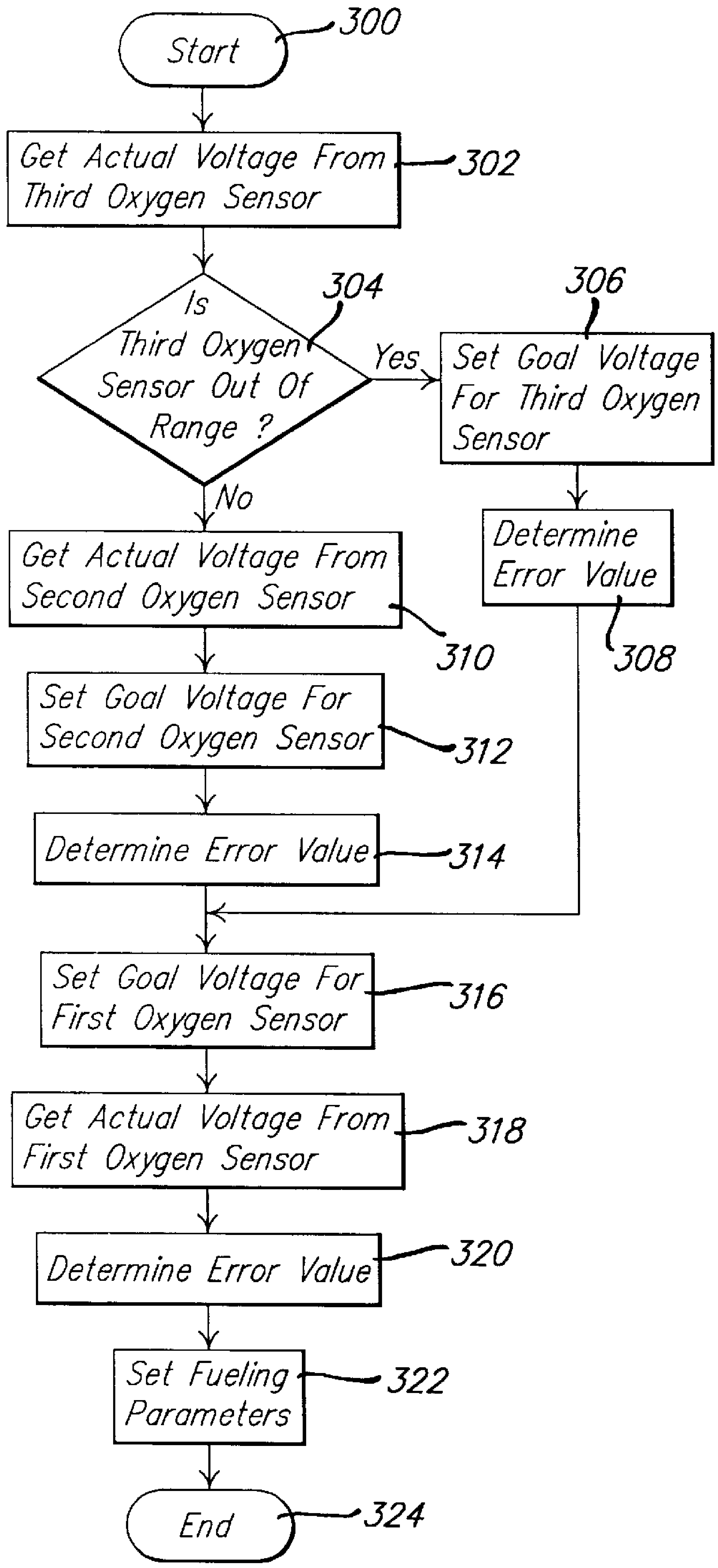

Start
300
Get Actual Voltage From Third Oxygen Sensor
302
Is Third Oxygen Sensor Out Of Range ?
304
Yes
Set Goal Voltage For Third Oxygen Sensor
306
Determine Error Value
308
No
Get Actual Voltage From Second Oxygen Sensor
310
Set Goal Voltage For Second Oxygen Sensor
312
Determine Error Value
314
Set Goal Voltage For First Oxygen Sensor
316
Get Actual Voltage From First Oxygen Sensor
318
Determine Error Value
320
Set Fueling Parameters
322
End
324

FIG. 5.

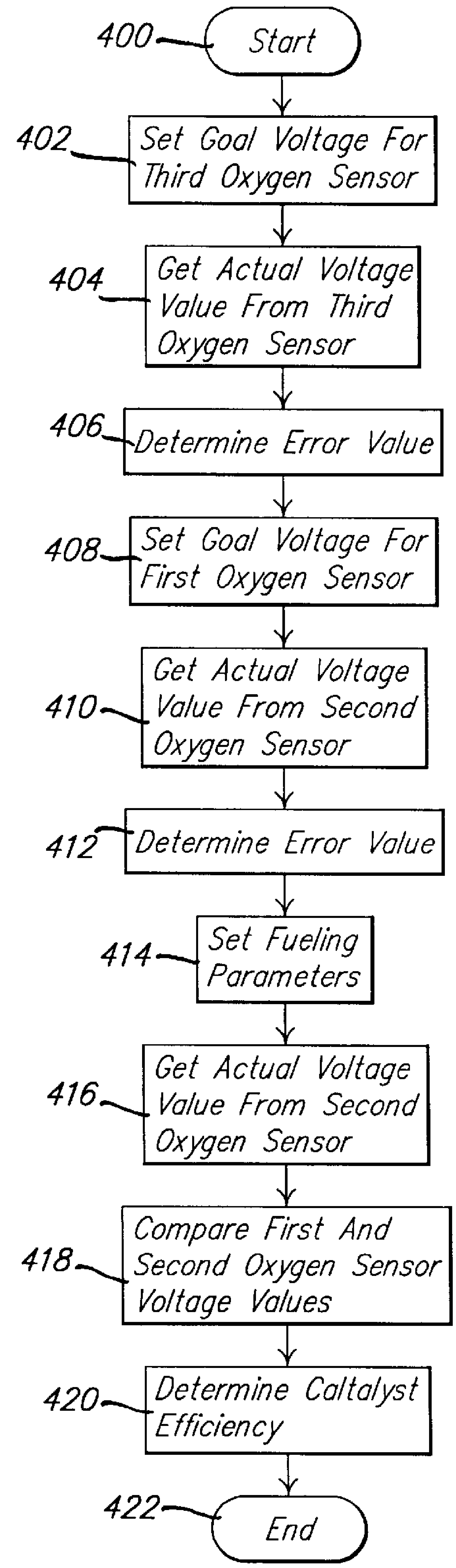

400
Start
402
Set Goal Voltage For Third Oxygen Sensor
404
Get Actual Voltage Value From Third Oxygen Sensor
406
Determine Error Value
408
Set Goal Voltage For First Oxygen Sensor
410
Get Actual Voltage Value From Second Oxygen Sensor
412
Determine Error Value
414
Set Fueling Parameters
416
Get Actual Voltage Value From Second Oxygen Sensor
418
Compare First And Second Oxygen Sensor Voltage Values
420
Determine Caltalyst Efficiency
422
End

FIG. 6.

TRIPLE OXYGEN SENSOR ARRANGEMENT

BACKGROUND OF THE INVENTION

1. Technical Field

The present invention generally relates to emission control systems and, more particularly, to oxygen sensor-based emission control systems for automotive vehicles.

2. Discussion

Operation of an internal combustion engine causes certain exhaust elements to be generated. For instance, hydrocarbons (HC) and nitrous oxide (NOx) emissions are produced. Certain air quality management plans dictate that such emissions be controlled to within pre-selected limits.

To reduce the amount of undesirable emissions passing through an engine exhaust system to the atmosphere, modern motor vehicles employ a catalytic converter. The catalytic converter fosters a reaction wherein undesirable emission elements are converted to different elements prior to their passage to the atmosphere. To monitor the efficiency of the catalytic converter, sensors are sometimes employed.

For example, an oxygen sensor may be disposed upstream of a catalyst in the catalytic converter so that the nature of the exhaust gasses entering the catalyst may be determined. If the constituents of the exhaust gas are not within a desirable range, the output of the oxygen sensor is used to modify the fuel-to-air ratio within the engine. Often, this entails increasing or decreasing the amount of fuel injected by the fuel injectors in the engine. As a result, the constituents within the exhaust gas are modified.

Similarly, by disposing an oxygen sensor downstream of the catalyst, the constituents of the exhaust gas exiting the catalyst can be learned. If the constituents are not within the desired range, the fuel-to-air ratio within the engine can be modified. Further, by placing a first oxygen sensor upstream of the catalyst and a second oxygen sensor downstream of the catalyst, the nature of the exhaust gas through the catalyst can be learned. As such, greater control of the fuel-to-air ratio within the engine may be exercised to modify the exhaust constituents.

In some automotive vehicles, a second catalyst brick is employed in the catalytic converter can downstream of the first catalyst brick. In combination with such an arrangement, a first oxygen sensor has been placed upstream of the first catalyst and a second oxygen sensor has been disposed downstream of the first catalyst and upstream of the second catalyst. This is the so-called "mid-brick" position. While this configuration has provided beneficial results for learning the constituents through the first catalyst and entering the second catalyst, there is room for improvement in the art.

For example, it would be desirable to provide a configuration that enables learning of the constituents through the second catalyst thereby enhancing control of the level of nitrous oxide passing through the system.

SUMMARY OF THE INVENTION

The above and other objects are provided by an exhaust system including two catalysts and three oxygen sensors. The second catalyst is disposed downstream of the first catalyst. The first oxygen sensor is disposed upstream of the first catalyst, the second oxygen sensor is disposed downstream of the first catalyst and upstream of the second catalyst, and the third oxygen sensor is disposed downstream of the second catalyst. A goal voltage corresponding to a desired level of nitrous oxide within the exhaust is

provided for the third oxygen sensor. This goal voltage is based on engine RPM and MAP. The engine controller compares the goal voltage to an actual voltage generated by sensing the level of oxygen downstream of the second catalyst. Based on this comparisons an error value between the goal voltage and the actual voltage is obtained. This error value is converted into a goal voltage for the first oxygen sensor. An actual voltage generated by the first oxygen sensor sensing the a mount of oxygen upstream of the first catalyst is compared to the goal voltage derived from the third oxygen sensor. The difference between the goal voltage and actual voltage is used to modulate the pulse width of a signal sent to the fuel injectors of an engine such that the amount of fuel delivered by the fuel injectors is modified. The second oxygen sensor generates an actual voltage corresponding to the amount of oxygen the second oxygen sensor senses downstream of the first catalyst and upstream of the second catalyst. Changes in the actual voltage generated by the second oxygen sensor are compared to changes in the actual voltage generated by the first oxygen sensor. By monitoring the nature of these changes as they relate to one another, the performance of the first catalyst can be determined.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to appreciate the manner in which the advantages and objects of the invention are obtained, a more particular description of the invention will be rendered by reference to specific embodiments there of which are illustrated in the appended drawings. Understanding that these drawings only depict preferred embodiments of the present invention and are not therefore to be considered limiting in scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. **1** is a schematic illustration of an exhaust system in accordance with the present invention;

FIG. **2** is a schematic illustration of the control system for use in conjunction with the exhaust system of FIG. **1**;

FIG. **3** is a flowchart illustrating a first embodiment methodology of the present invention;

FIG. **4** is a flowchart illustrating a second embodiment methodology of the present invention;

FIG. **5** is a flowchart illustrating a third embodiment methodology of the present invention; and

FIG. **6** is a flowchart illustrating a fourth embodiment methodology of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention is directed towards a fuel control system for a motor vehicle engine. The fuel control system includes multiple oxygen sensors disposed at pre-selected locations relative to a pair of catalysts along an exhaust system coupled to the engine. By relating the results of one oxygen sensor to another, greater control of the fuel system is provided thereby enabling greater control over exhaust emissions. Further, by comparing the outputs from one oxygen sensor to another, the performance of the catalyst may be determined.

Turning now to the drawing figures, FIG. **1** schematically illustrates an exhaust system for an automotive vehicle generally at **10**. The exhaust system **10** includes an exhaust pipe **12** connected to an internal combustion engine **14** at a first end and terminating in a muffler **16** at a second end. A first or upstream catalyst **18** is disposed along the exhaust pipe **12** between the engine **14** and muffler **16**. A second or downstream catalyst **20** is disposed along the exhaust pipe **12** downstream of the first catalyst **18** and upstream of the muffler **16**.

A first or upstream oxygen sensor **22** is disposed along the exhaust pipe **12** upstream of the first catalyst **18**. A second or mid-brick oxygen sensor **24** is disposed downstream of the first catalyst **18** and upstream of the second catalyst **20**. A third or downstream oxygen sensor **26** is disposed downstream of the second catalyst **20**.

The first oxygen sensor **22**, second oxygen sensor **24**, and third oxygen sensor **26** are electrically connected to a controller **28** such as the ECU. The controller **28** also communicates with a fuel delivery system **30** associated with the engine **14**. Preferably, the fuel delivery system **30** is in the form of fuel injectors.

Turning now to FIG. **2**, a schematic illustration of a control system for the exhaust system **10** of FIG. **1** is shown generally at **32**. Preferably, the control system **32** is implemented in a controller such as the controller **28** of FIG. **1**. Initially, the third oxygen sensor **26** determines the amount of oxygen in the exhaust downstream of the second catalyst. The level of oxygen sensed by the third oxygen sensor **26** manifests itself as a voltage signal generated by the third oxygen signal, for example 500–900 mv. The voltage signal from the third oxygen sensor **26** is passed through a signal linearization step **34** where the signal is converted to a more usable form.

The linearized signal from step **34** is sent to a comparator **36**. The comparator **36** also receives a goal voltage signal from a table **38**. The table **38** includes a plurality of voltages therein corresponding to engine RPM and MAP. As such, depending on the engine RPM and MAP, a different goal voltage for the third oxygen sensor **26** is provided from the table **38**. At the comparator **36**, the linearized voltage from the third oxygen sensor **26** is compared to the goal voltage from table **38**. The difference therebetween represents an error value.

The error value from comparator **36** is sent to a proportional calculation block **40** and an integral calculation block **42**. The proportionalized error value and the integrated error value are forwarded from blocks **40** and **42** to comparator **44**. The comparator **44** also receives a default downstream oxygen sensor goal from block **46**. This default goal represents a fairly optimized goal voltage for the second oxygen sensor to be used when the third oxygen sensor output is unreliable (during warm-up, for example).

The comparator **44** also receives an oxygen adaptive off-set value from block **48**. The adaptive off-set value at block **48** is learned over time to further optimize goal voltage for the second oxygen sensor when the third oxygen sensor output is unreliable. The comparator **44** combines the default downstream oxygen sensor goal value from block **46**, the integrated error value from block **42**, the proportionalized error value from block **40**, and the adaptive off-set value from block **48** into a second oxygen sensor goal value.

The second oxygen sensor goal value is forwarded from comparator **44** to comparator **50**. The comparator **50** also receives a linearized voltage signal from the second oxygen sensor **24** after it passes through a downstream oxygen sensor signal linearization step **52**. The linearized voltage signal corresponds to an amount of oxygen in the exhaust sensed by the second oxygen sensor **24** between the first and second catalysts. According to this configuration, the output signal from the third oxygen sensor **26** becomes a basis for the goal voltage for the second oxygen sensor **24**.

The difference between the goal voltage dictated by the third oxygen sensor **26** and the actual voltage sensed by the second oxygen sensor **24** determined at comparator **50** is sent to a proportional calculation block **54** and an integral calculation block **56**. The proportionalized error signal from block **54** and integrated error signal from block **56** are sent to a comparator **58**. The comparator **58** also receives a default upstream oxygen sensor goal value from block **60**. This default goal value represents a fairly optimized goal voltage for the first oxygen sensor to be used when the second oxygen sensor output is unreliable (during warm-up, for example).

The comparator **58** also receives an oxygen sensor adaptive offset value from block **62**. This offset value is learned over time to further optimize goal voltage for the first oxygen sensor when the second oxygen sensor output is unreliable. The comparator **58** combines the default goal value from block **60**, the integrated error value from block **56**, the proportionalized error value from block **54**, and the adaptive offset value from block **62** into a first oxygen sensor goal value.

The first oxygen sensor goal value is sent from comparator **58** to comparator **64**. As such, the output signal from the second oxygen sensor **24** becomes the basis for the goal voltage for the first oxygen sensor **22**. An actual value of oxygen in the exhaust sensed by the first oxygen sensor **22** upstream of the first catalyst is sent as a voltage signal to an upstream oxygen sensor signal linearization step **66**. The linearized voltage signal is sent from step **66** to the comparator **64** where an error value between the actual value sensed by the first oxygen sensor **22** and the goal value dictated by the second oxygen sensor **24** is determined.

The error value from comparator **64** is sent to a proportional calculation block **68**, an integral calculation block **70**, and a derivative calculation block **72**. The proportionalized error value from block **68**, the integrated error value from block **70**, and the derivative error value from block **72** are sent to a comparator **74**. The comparator **74** also receives a kicks value from block **76**. The kicks value **76** represents an induced perturbation to insure feedback activity. The kicks value is a fast-acting initial correction applied once each time the error value from comparator **64** changes polarity (as from richer-than-goal to leaner-than-goal). The kicks is a remnant of past control practices. It is retained in the present invention for optional use.

The output from comparator **74** is interpreted by the engine controller as a percent-correction and applied to the pulsewidth modulated output to the fuel delivery system **30** of FIG. **1**. The pulse-width of the output signal controls the amount of fuel injected into the engine **14**. By increasing and/or decreasing the amount of fuel injected, the fuel-to-air ratio in the engine is varied thereby changing the exhaust gas constituents.

Referring now to FIG. **3**, a flow chart depicting a control methodology for operating the system of FIGS. **1** and **2** is illustrated. The methodology starts in bubble **100** and falls through to block **102**. In block **102**, the methodology sets the goal voltage value for the third oxygen sensor. This goal voltage value is preferably one of a plurality of goal voltages stored in a table and corresponding to engine RPM and MAP. From block **102**, the methodology advances to block **104**.

In block **104**, the methodology reads an actual voltage value generated from the third oxygen sensor. This actual voltage value corresponds to the amount of oxygen sensed by the third oxygen sensor flowing through the exhaust system downstream of the second catalyst. From block **104**, the methodology advances to block **106**.

In block **106**, the methodology compares the goal voltage value from block **102** to the actual voltage value from block **104**. The difference between the goal voltage value from the table and the actual voltage value generated by the third oxygen sensor is converted into an error value. From block **106**, the methodology continues to block **108**.

At block **108**, the methodology sets the goal voltage value for the second oxygen sensor based on the error value from block **106**. As such, the output signal from the third oxygen sensor is used to dictate the goal value for the second oxygen sensor. From block **108**, the methodology continues to block **110**.

In block **110**, the methodology obtains the actual voltage value from the second oxygen sensor. This actual voltage value is generated by the second oxygen sensor sensing an amount of oxygen in the exhaust system between the first catalyst and the second catalyst. From block **110**, the methodology continues to block **112**.

In block **112**, the methodology compares the second oxygen sensor goal voltage value to the actual voltage value from the second oxygen sensor. The difference between the goal voltage value from block **108** and the actual voltage value from block **110** is converted into an error value. From block **112**, the methodology continues to block **114**.

In block **114**, the methodology sets the goal voltage value for the first oxygen sensor based on the error value from block **112**. As such, the output signal from the second oxygen sensor is used to dictate the goal value for the first oxygen sensor. From block **114**, the methodology continues to block **116**.

In block **116**, the methodology obtains an actual voltage value from the first oxygen sensor. The actual voltage value is generated by the first oxygen sensor sensing an amount of oxygen in the exhaust upstream of the first catalyst. From block **116**, the methodology advances to block **118**.

In block **118**, the methodology compares the first oxygen sensor goal voltage value to the actual voltage value from the first oxygen sensor. The difference between the goal voltage value from block **114** and the actual voltage value from block **116** is converted into an error value. From block **118**, the methodology advances to block **120**.

In block **120**, the methodology sets the fueling parameters for the engine according to the error value from block **118**. Preferably, the fueling parameters are controlled by varying (i.e., modulating) the pulse-width of a signal sent from the engine controller to the fuel injectors. By controlling the amount of fuel injected, the fuel-to-air ratio within the engine is adjusted and the constituents of the engine emissions are modified. After setting the fueling parameters in block **120**, the methodology continues to bubble **122** where it exits the subroutine pending a subsequent execution thereof.

Referring now to FIG. **4**, an alternate embodiment control methodology for the exhaust system of FIGS. **1** and **2** is illustrated. This methodology is similar to the methodology of FIG. **3** with the exception that no error is calculated for the third oxygen sensor. Instead, the third oxygen sensor is characterized as high, low, or intermediate with respect to two threshold voltage levels causing one of three possible goal voltages to be applied to the second oxygen sensor. The methodology starts in bubble **200** and falls through to block **202**.

In block **202**, the methodology obtains an actual voltage value from the third oxygen sensor. The actual voltage value is generated by the third oxygen sensor sensing an amount of oxygen in the exhaust downstream of the second catalyst. From block **202**, the methodology advances to decision block **204**.

In block **204**, the methodology compares the actual voltage value from block **202** to a low threshold value. The low voltage threshold value delineates a boundary between neutral and lean exhaust composition. If the actual voltage value generated by the third oxygen sensor is less than the low voltage threshold value, the methodology advances to decision block **206**. In block **206**, a rich goal voltage is set for the second oxygen sensor.

Referring again to decision block **204**, if, however, the actual voltage value from the third oxygen sensor is greater than or equal to the low voltage threshold value, the methodology advances to block **208**. In decision block **208**, the methodology compares the actual voltage value from the third oxygen sensor to a high voltage threshold value. The high voltage threshold value corresponds to a boundary between neutral and rich exhaust composition. If the actual voltage value from the third oxygen sensor is greater than the high voltage threshold value, the methodology advances to block **210**. In block **210**, a lean goal voltage is set for the second oxygen sensor.

Referring again to decision block **208**, if, however, the actual voltage value from the third oxygen sensor is less than or equal to the high voltage threshold value, the methodology advances to block **212**. In block **212**, a neutral goal voltage is set for the second oxygen sensor. From blocks **206**, **210**, and **212**, the methodology continues to block **214**.

In block **214**, the methodology obtains the actual voltage value from the second oxygen sensor. The actual voltage value is generated by the second oxygen sensor sensing the amount of oxygen in the exhaust between the first and second catalysts. From block **214**, the methodology continues to block **216**.

In block **216**, the methodology compares the goal voltage value from blocks **206**, **210**, or **212** to the actual voltage value from block **214**. The difference between the goal voltage value and the actual voltage value is then converted into an error value. From block **216**, the methodology advances to block **218**.

In block **218**, the methodology sets the goal voltage value for the first oxygen sensor according to the error value determined at block **216**. As such, the output from the second oxygen sensor is used as a basis for the goal voltage value for the first oxygen sensor. From block **218**, the methodology advances to block **220**.

In block **220**, the methodology obtains the actual voltage value from the first oxygen sensor. The actual voltage value corresponds to an amount of oxygen sensed in the exhaust upstream of the first catalyst by the first oxygen sensor. From block **220**, the methodology advances to block **222**.

In block **222**, the methodology compares the goal voltage value from block **218** to the actual voltage value from block **220**. The difference between the goal voltage value and the actual voltage value is then converted into an error value. From block **222**, the methodology advances to block **224**.

In block **224**, the methodology sets the fueling parameters for the engine according to the error value determined at block **222**. Preferably, this is accomplished by pulse width modulating a signal sent from the engine controller to the fuel delivery system in accordance with the error value. From block **224**, the methodology advances to bubble **226** and exits the subroutine pending a subsequent execution thereof.

Referring now to FIG. **5**, another alternate embodiment control methodology for the exhaust system of FIGS. **1** and **2** is illustrated. This methodology is similar to the previous embodiments except the third oxygen sensor is only employed when its actual value is outside of a pre-selected range. When the actual voltage of the third oxygen sensor is outside of a pre-selected range, the second oxygen sensor is ignored and fueling is controlled by the first and third oxygen sensors. When the actual voltage of the third oxygen sensor is inside of the pre-selected range, fueling is controlled by the first and second sensors. This enables fueling adjustments to be made for control of exhaust composition downstream from the second catalyst only when exhaust composition at that location deviates significantly from the desired composition, simplifying the control methodology from previously described control methodology embodiments. Fueling adjustments are made for control of exhaust composition downstream from the first catalyst and upstream from the second catalyst at all other times.

The methodology starts in bubble **300** and falls through to block **302**. In block **302**, the methodology obtains the actual voltage value from the third oxygen sensor sensing the level of oxygen in the exhaust downstream of the second catalyst. From block **302**, the methodology advances to decision block **304**.

In decision block **304**, the methodology compares the actual voltage value from the third oxygen sensor obtained at block **302** to a range of voltage values. Preferably, this range is defined by an upper voltage threshold and a lower voltage threshold. If the voltage threshold is outside of the pre-selected range at decision block **304** (i.e., less than the minimum range value or greater than the maximum range value), the methodology advances to block **306**. This range of values corresponds to a range outside of which the second catalyst cannot be expected to satisfactorily eliminate exhaust pollutants.

In block **306**, the methodology sets the goal voltage value for the third oxygen sensor. This goal voltage value is preferably one of a plurality of goal voltages stored in a table and corresponding to engine RPM and MAP. From block **306**, the methodology advances to block **308**.

In block **308**, the methodology compares the goal voltage value from block **306** to the actual voltage value from block **302**. The difference between the goal voltage value from the table and the actual voltage value generated by the third oxygen sensor is converted into an error value.

Referring again to decision block **304**, if, however, the voltage threshold is not outside of the pre-selected range (i.e., greater than or equal to the minimum range value and less than or equal to the maximum range value), the methodology advances to block **310**.

In block **310**, the methodology obtains the actual voltage value for the second oxygen sensor sensing the level of oxygen in the exhaust downstream of the first catalyst and upstream from the second catalyst. From block **310**, the methodology advances to block **312**.

In block **312**, the methodology sets the goal voltage value for the second oxygen sensor. This goal voltage value is preferably one of a plurality of goal voltages stored in a table and corresponding to engine RPM and MAP. From block **312**, the methodology advances to block **314**.

In block **314**, the methodology compares the goal voltage value from block **312** to the actual voltage value from block **310**. The difference between the goal voltage value from the table and the actual voltage value generated by the second oxygen sensor is converted into an error value. From blocks **308** and **314**, the methodology advances to block **316**.

In block **316**, the methodology sets the goal voltage value for the first oxygen sensor according to the error value from block **308** or block **314**. Thus, the output of the second oxygen sensor or the third sensor becomes the basis for the goal voltage value for the first oxygen sensor. From block **316**, the methodology continues to block **318**.

In block **318**, the methodology obtains the actual voltage value from the first oxygen sensor. The actual voltage value corresponds to an amount of oxygen sensed in the exhaust upstream of the first catalyst by the first oxygen sensor. After obtaining the actual voltage value from the first oxygen sensor at block **318**, the methodology continues to block **320**.

In block **320**, the methodology compares the goal voltage value for the first oxygen sensor from block **316** to the actual voltage value from the first oxygen sensor from block **318**. The difference between the goal voltage value and the actual voltage value is then converted into an error value. After determining the error value at block **320**, the methodology advances to block **322**.

In block **322**, the methodology sets the fueling parameters for the engine according to the error value from block **320**. Preferably, this is accomplished by pulse width modulating a signal sent from the engine controller to the fuel delivery system in accordance with the error value. From block **322**, the methodology advances to bubble **324** and exits the subroutine pending a subsequent execution thereof.

Referring now to FIG. **6**, a methodology of utilizing the outputs of the first and second oxygen sensors to determine the general state of the catalytic converters functioning is illustrated. In this embodiment the second oxygen sensor is only used for monitoring catalyst efficiency and is not used in fuel control. Rather, the output signal from the third oxygen sensor is used to set the goal voltage value for the first oxygen sensor. The methodology starts in bubble **400** and falls through to block **402**.

In block **402**, the methodology sets the goal voltage value for the third oxygen sensor. This goal voltage value is preferably obtained from a table including a plurality of pre-selected values and is selected according to engine RPM and MAP. From block **402**, the methodology continues to block **404**.

In block **404**, the methodology obtains the actual voltage value from the third oxygen sensor. The actual voltage value is generated by the third oxygen sensor sensing the oxygen level in the exhaust downstream of the second catalyst. From block **404**, the methodology advances to block **406**.

In block **406**, the methodology compares the goal voltage value from block **402** to the actual voltage value from block **404**. The difference between the goal voltage value and the actual voltage value is then converted into an error value. From block **406**, the methodology advances to block **408**.

In block **408**, the methodology sets the goal voltage value for the first oxygen sensor according to the error value from block **406**. As such, the output signal of the third oxygen sensor is used for setting the goal voltage value for the first oxygen sensor. From block **408**, the methodology advances to block **410**.

In block **410**, the methodology obtains the actual voltage value from the first oxygen sensor. The actual voltage value is generated by the first oxygen sensor sensing the level of oxygen upstream of the first catalyst. From block **410**, the methodology advances to block **412**.

In block **412**, the methodology compares the goal voltage value for the first oxygen sensor from block **408** to the actual voltage value from the first oxygen sensor from block **410**. The difference between the goal voltage value and the actual voltage value is then converted into an error value at block **412**. From block **412**, the methodology advances to block **414**.

In block **414**, the methodology sets the fueling parameters for the engine according to the error value generated at block **412**. Preferably, the fueling parameters are controlled by pulse width modulating a signal sent to the fuel injectors of the engine. From block **414**, the methodology continues to block **416**.

In block **416**, the methodology obtains the actual voltage value from the second oxygen sensor. The actual voltage value is generated by the second oxygen sensor sensing the level of oxygen in the exhaust downstream of the first catalyst and upstream of the second catalyst. From block **416**, the methodology advances to block **418**.

In block **418**, the methodology compares the actual voltage value for the first oxygen sensor from block **410** to the actual voltage value from the second oxygen sensor from block **416**. The difference over time between the actual voltage values of the first and second oxygen sensors is used to infer an efficiency of the first catalyst. From block **418**, the methodology advances to block **420**.

In block **420**, the methodology determines the efficiency of the first catalyst. Preferably, this is accomplished by comparing the wide swings of the actual voltage values for the first oxygen sensor to the relatively smooth swings of the actual voltage values for the second oxygen sensor. From block **420**, the methodology continues to bubble **422** where it exits the subroutine pending a subsequent execution thereof.

Thus, the present invention provides an exhaust system including a plurality of oxygen sensors. The output from one oxygen sensor is used in setting the goal voltage value for another oxygen sensor. As such, the fueling parameters of an engine may be varied to control the nature of the emissions passing through the exhaust system. Further, the outputs from the sensors are compared to determine the functioning of the catalyst.

Those skilled in the art can now appreciate from the foregoing description that the broad teachings of the present invention can be implemented in a variety of forms. Therefore, while this invention has been described in connection with particular examples thereof, the true scope of the invention should not be so limited since other modifications will become apparent to the skilled practitioner upon a study of the drawings, specification, and following claims.

What is claimed is:

1. An exhaust system comprising:

a first oxygen sensor;

a first catalyst disposed downstream of said first oxygen sensor;

a second oxygen sensor disposed downstream of said first catalyst;

a second catalyst disposed downstream of said second oxygen sensor; and

a third oxygen sensor disposed downstream of said second catalyst;

wherein said first oxygen sensor outputs a signal for controlling fuel delivery, said signal used to calculate a difference between a goal value for said first oxygen sensor and an actual value determined by said first oxygen sensor;

wherein said goal value is dictated by said third oxygen sensor; and

wherein said goal value output for said first oxygen sensor corresponds to a difference between a second goal value for said third oxygen sensor and an actual value determined by said third oxygen sensor.

2. The system of claim **1** wherein said second goal value is one of a plurality of pre-selected goal values corresponding to a range of operating parameters of an engine associated with said exhaust system.

3. The system of claim **1** wherein said first oxygen sensor generates a first oxygen sensor actual value and said second oxygen sensor generates a second oxygen sensor actual value, a difference between said first and second oxygen sensor actual values corresponding to a performance of said first catalyst.

4. The system of claim **3** wherein said first oxygen sensor actual value corresponds to an amount of oxygen sensed by said first oxygen sensor upstream of said first catalyst, and said second oxygen sensor actual value corresponding to an amount of oxygen sensed by said second oxygen sensor downstream of said first catalyst.

5. A method for controlling an amount of fuel delivered by a fuel system to an engine and for monitoring catalyst performance comprising:

providing an exhaust system associated with said engine with a first oxygen sensor communicating with said fuel system, a first catalyst downstream of said first oxygen sensor, a second oxygen sensor downstream of said first catalyst, a second catalyst downstream of said second oxygen sensor, and a third oxygen sensor downstream of said second catalyst;

determining a third oxygen sensor error value between a third oxygen sensor goal value for to said third oxygen sensor and a third oxygen sensor actual value determined by said third oxygen sensor;

outputting said third oxygen sensor error value as a first oxygen sensor goal value;

determining a first oxygen sensor error value between said first oxygen sensor goal value and a first oxygen sensor actual value determined by said first oxygen sensor;

outputting said first oxygen sensor error value as a control signal to said fuel system for varying said amount of fuel delivered to said engine;

determining a difference value between said first oxygen sensor actual value and a second oxygen sensor actual value determined by said second oxygen sensor; and

outputting said difference value as a performance indicator for said first catalyst.

6. The method of claim **5** wherein said third oxygen sensor goal value further comprises one of a plurality of pre-selected goal values corresponding to an RPM and MAP condition of said engine.

7. The method of claim **5** wherein said third oxygen sensor goal value further comprises a voltage of said third oxygen sensor corresponding to a desired level of oxygen in said exhaust system downstream of said second catalyst.

8. The method of claim **5** wherein said third oxygen sensor actual value further comprises a voltage of said third oxygen sensor generated according to an amount of oxygen sensed in said exhaust system downstream of said second catalyst.

9. The method of claim **5** wherein said first oxygen sensor actual value further comprises a voltage of said first oxygen sensor generated according to an amount of oxygen sensed in said exhaust system upstream of said first catalyst.

10. The method of claim **5** wherein said second oxygen sensor actual value further comprises a voltage of said second oxygen sensor generated according to an amount of oxygen sensed in said exhaust system downstream of said first catalyst and upstream of said second catalyst.

11. The method of claim **5** wherein said step of varying said amount of fuel delivered by said fuel system further comprises pulse width modulating said control signal sent to said fuel system according to said first oxygen sensor error value.

12. A method of controlling fuel delivery to an engine and montoring catalyst efficiency based on engine exhaust feedback control comprising:

providing an exhaust system for said engine with a first catalyst and a second catalyst, said second catalyst disposed downstream of said first catalyst;

providing said exhaust system with a first oxygen sensor a second oxygen sensor, and a third oxygen sensor, said first oxygen sensor disposed upstream of said first catalyst and communicating with a fuel delivery mechanism of said engine, said second oxygen sensor disposed downstream of said first catalyst and upstream of said second catalyst, said third oxygen sensor disposed downstream of said second catalyst;

wherein a third oxygen sensor output value is input as a first oxygen sensor goal value for said first oxygen sensor and a first oxygen sensor output value is used to vary said fuel delivery, and wherein a difference value between a first oxygen sensor output value and a second oxygen sensor output value is employed as an efficiency indicator for said first catalyst; and

wherein a third oxygen sensor goal value is determined for said third oxygen sensor, said third oxygen sensor goal value corresponding to an RPM and MAP condition of said engine.

13. The method of claim **12** wherein a difference between said third oxygen sensor output value and a first oxygen sensor actual value determined by said first oxygen sensor is converted into a first oxygen sensor error value which is used to vary said fuel delivery.

14. The method of claim **12** wherein said first oxygen sensor output value is used to pulse width modulate a signal to control said fuel delivery.

15. The method of claim **12** wherein said third oxygen sensor output value corresponds to an error value between said third oxygen sensor goal value and a third oxygen sensor actual value generated by said third oxygen sensor sensing an amount of oxygen downstream of said second catalyst, and wherein said first oxygen sensor output value corresponds to an error value between said first oxygen sensor goal value and a first oxygen sensor actual value generated by said first oxygen sensor sensing an amount of oxygen upstream of said first catalyst.

16. The method of claim **12** wherein said second oxygen sensor output value corresponds to a second oxygen sensor actual value generated by said second oxygen sensor sensing an amount of oxygen downstream of said first catalyst and upstream of said second catalyst, and wherein said first oxygen sensor output value corresponds to a first oxygen sensor actual value generated by said first oxygen sensor sensing an amount of oxygen upstream of said first catalyst.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,253,541 B1
DATED : July 3, 2001
INVENTOR(S) : Sullivan et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
Item [75], line 5, add inventor "**Mark J. Poublon**, Shelby Twp., MI"

Signed and Sealed this

Twenty-sixth Day of March, 2002

Attest:

JAMES E. ROGAN
Director of the United States Patent and Trademark Office

Attesting Officer